# Geo Risk Management – A New Engineering Education Approach

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ABSTRACT: This paper presents the main structure and content of the new Geo Risk Management lectures. Geo Risk Management is part of the core curriculum of the MSc in GeoEngineering, as provided by the faculty of Civil Engineering and Applied Earth Sciences of the Delft University of Technology in the Netherlands.

After a general introduction, and some attention to education and geo risk management, this paper presents an overview of the content of the MSc course. The Geo Risk Management course is subdivided in two main parts. Part one concerns the theoretical part of geotechnical risk management. Part two of the Geo Risk Management lectures covers the practical part, by exploring a number of specific topics.

This paper will largely focus on part one, the more theoretical part of the course, because the content and approach of this part proved to be the most deviating from the other MSc courses. The paper ends with one main conclusion about this yet hardly explored adventure of teaching risk *management*, rather than the more conventional risk *analysis*, to MSc students.

## 1 INTRODUCTION

Today's global construction industry is facing a serious rise in complexity. This situation is caused by an ever increasing demand on qualities, functions, safety, sustainability, as well as tight cost and planning control in all sorts of construction projects. Furthermore, changing interests and perceptions of the many stakeholders of construction projects do not only create even more complexity. These dynamics increase also the already abundantly available uncertainties in most construction projects, ranging from market and thus cost and profit fluctuations to rather unexplored subsoil conditions. Such uncertainties occur during the entire process of realisation of any construction project, from the earliest feasibility studies towards operation and maintenance of the realised project.

Ground conditions are widely acknowledged as one of the main uncertainties or risk factors in most construction projects. Actual ground conditions and consequential behavior are inherently difficult to predict, as these can and will only reveal during the construction and operation phases. However, in those stages, any remediation measures to cope with differing ground conditions are often expensive and time consuming, if possible at all. As for instance mentioned by Fookes et al (2000), numerous case histories over the last century show that failure to anticipate ground conditions is a main factor in construction problems.

Probably quite remarkable for engineers, causes of failure in many projects are not of *technical* origin. For instance, a recent study of Bea (2006) highlights the dominant role of the *people factor* in geotechnical engineering and construction failures. His findings are based on more than 600 well-documented cases of failing civil engineering projects over almost 20 years. In some 80 % of the cases failure has been caused by non-technical factors, such as human, organizational and knowledge uncertainties. These results align with similar findings by Sowers (1993). His study of more than 500 well documented foundation failures showed that 88 % of them were caused by human shortcomings. The remaining 12 % was caused by a lack of technology. It appears that effective construction project *management* is as least as important as effective construction *technology*. In other words, severe *blending* of technical and managerial subjects will be required for realizing successful projects that effectively deal with the presented challenges. We seem therefore desperately in need of a new engineering education approach, at least when it comes to geotechnical engineering and construction.

The main objective of this paper is to inspire professionals in academia and the industry to develop or to attend courses that blend (geotechnical) risk analysis with (geotechnical) risk management. Such courses may be undergraduate MSc courses, post-graduate courses or summer courses. The latter two types may become particularly useful to the daily practices of professionals within the construction industry.

## 2 EDUCATION AND GEO RISK MANAGEMENT

### 2.1 *The need for risk management education*

In many parts of the world there are already promising responses to today's demanding construction industries. In Europe, national changes initiatives to strengthen the construction industry have been started over the last years in countries such as the UK, Denmark, Finland, Norway and The Netherlands. Outside Europe similar initiatives are running in for instance Australia, Hong Kong, and Singapore.

One of the answers to today's and tomorrows challenges is the well-structured application of risk management in general and geotechnical risk management in particular. For becoming really effective, risk management should be embedded and consistently applied in *all* phases of a construction project. Within the construction industry, and in its education as well, attention to continuous risk *management*, rather than a few moments of risk *analysis* is still rather new. Starting to *educate* this awareness, followed by how to apply and continue risk management, is of paramount importance. Practising professionals, but in particular students, should become educated in trained in the basic risk management principles and practices. Only then the next generation of engineering and construction professionals will be able to properly answer the ever increasing demands of construction.

### 2.2 *A new MSc course - GeoEngineering*

In September 2006, the faculty of Civil Engineering and Applied Earth Sciences of the Delft University of Technology started their brand new MSc in GeoEngineering. At present, the GeoEngineering section includes five chairs: Ground Mechanics, Groundwater Mechanics, Foundation Engineering, Underground Space Technology, and Engineering Geology. This Geo Risk Management course is part of the core curriculum of the MSc in GeoEngineering, which means that any student aiming to complete a MSc in Geo Engineering has to follow it.

Together with Fugro's Martin van der Meer, the author of this paper developed and lectures the Geo Risk Management course. The course is founded on our extensive professional experiences, in The Netherlands and abroad.

The author took the first rather theoretical part and his co-creator was responsible for the second and more practical part of the lectures. Additionally, prof. Johan Bosch of the Delft University of Technology and dr. Gerard van Meurs of Deltares, provided a guest lecture each. The Geo Risk Management lectures were for the first time provided in February and March of 2007.

### 2.3 *Objective of Geo Risk Management*

Geo Risk Management aims to teach the student in particular *why* and *how* to apply structured management of ground-related risk during the entire process of any construction project. After following the course, any student should be aware of the inherent risk of ground within civil engineering and construction, including the impact and difficulties of the people factor. Furthermore, the student should be able to apply principles of ground-related risk management during the entire project management process for a variety of civil engineering constructions. Such course objectives align and support the recommendations for developing the academic education for the construction industry towards more generic expertise. For instance, the Regieraad Bouw, a major Dutch construction industry committee, advocates to educate all-round civil engineers, who have also knowledge of less in-depth but critical subjects like project management. It seems that building risk management competencies, including awareness of the inherent complexity of the people factor, fits well within these industry needs.

### 2.4 *Two parts – theory serves practice*

The Geo Risk Management course is subdivided in two main parts. Part one concerns the theoretical part of geotechnical risk management. It explains the concepts of uncertainty, risk and risk management. This first part presents a flexible framework for geotechnical risk *management,* rather than more conventional risk *analysis*. The tried and tested GeoQ approach for ground-related risk management in construction projects serves as framework (van Staveren, 2006). This GeoQ risk management framework, where Q stands for maximising overall project quality, can and should ideally be applied in each phase of a construction project, from the earliest feasibility phase through to the operation and maintenance phase. The GeoQ risk management framework involves six generic project phases and six generic risk management steps. Abundant tools for facilitating the risk management processes are ready available.

Furthermore, the lectures during part one give a lot of attention to an often undervalued aspect of geotechnical engineering and construction: the *people factor*. Therefore, the role of individual professional engineers and their functioning in mono- and multidisciplinary teams are identified and explored during the lectures.

Part two covers a number of specific topics, merely based on certain types of geotechnical constructions. Examples are underground constructions, such as tunnels, water retaining structures, and infrastructural constructions, such as roads and railroads. This second part delivers a lot of geotechnical content for the risk management framework of part one. The focus of part two is on *how* to apply geotechnical risk management in our day-to-day practices. A lot of examples and cases demonstrate the pitfalls and the opportunities of ground-related risk management. In total, the course contains 12 blocks of lectures, with each block including two hours.

### 2.5 *The remaining part of this paper*

The content of the Geo Risk Management course seems worldwide quite new. Therefore, the lectures of part one and part two will be introduced in the remaining part of this paper. There is a focus on part one, the more theoretical part, because it proved to be the most deviating from the other courses of the MSc GeoEngineering at the Delft University of Technology. Van Staveren (2006) gives more detailed information about many of the aspects covered by the lectures and serves as the lecture's reference book.

Feedback of the students, as gained during running the course, is also shared with the readers. Such feedback may help us with (further) developing geotechnical risk management in general and its education and training in particular. The paper ends with one main conclusion.

## 3 GEO RISK MANAGEMENT - THEORY

### 3.1 *Lecture 1 - Introduction*

This first lecture aims to provide an overview of the new course on geotechnical risk management. After presenting the lecturers and the structure of the course, the first hour gives an introduction to the challenges and opportunities in the global construction industry. Major challenges presented are increasing complexity, the often still underdeveloped integrity and high failure costs, in which unexpected ground conditions have a serious stake. The many ongoing change initiatives world-wide provide interesting opportunities for the global construction industry, together with the adoption of rather new concepts, such as systems thinking and risk management.

The second hour serves as some kind of appetizer for the lectures to follow. It presents a variety of problems in a variety of projects world-wide, with one common element: the unexpected behavior of ground. There is one main message: ground is a (very) complicated foundation and construction material. Its inherent uncertainties and associated risks will never become completely eliminated. Therefore, we have to deal with these ground risks, which serves as the rationale and motivation for the remaining lectures.

### 3.2 *From uncertainty via risk to risk management*

Lecture 2 starts with presenting and discussing a number of relevant concepts: uncertainty, risk, risk management, ground, and finally ground risk management.

For instance, as set out by Blockley and Godfrey (2000), we should acknowledge three types of ground uncertainty: randomness, fuzziness and incompleteness. These terms are explained and related to the ground sampling and ground engineering practices. With regard to risk, three main different types of risk are introduced and explained. Having the ability to distinguish between these risk sets of pure and speculative risk, foreseen and unforeseen risk, and information and interpretation risk, will help any ground-related engineer a great deal with effectively managing these risks during the entire construction process.

Regarding to risk management, two of the main schools of risk management are explained: the *scientific* school and the *heuristic* or *rule of thumb* school of risk management. The latter has a more qualitative approach than the first one. Heuristic or rule of thumb risk management involves acknowledgement of experiences, engineering judgement and a certain degree of subjectivity. This paper does not allow to further explain and discuss such terminology. For instance, Van Staveren (2006) gives more detailed information.

Within the lecture, ground conditions are considered as including not only ground itself, but also ground water, any type of possible pollution, and man-made structures. Examples of the latter type are old foundation piles or buried pipelines.

Combining these concepts brings us to four main types of ground-related risk: geotechnical risks, geohydrological risks, geo-environmental risks and man-made obstruction risks. Consequently, ground risk management or geo risk management is defined as the overall application of policies, processes and practices dealing with ground-related risk. By the end of the first hour, the students should be able to define their own ground-related risks by clearly mentioning and distinguishing between the risk event, the risk cause, the probability of risk occurrence (quantitatively or qualitatively), and the expected risk effect.

The second hour presents the so-called GeoQ concept. With the Q of quality, GeoQ is a risk-driven approach to manage ground conditions and behaviour in a structured way for successfully completing any civil engineering project, during all project phases and for all stakeholders involved. GeoQ presents a flexible framework with six generic project phases and six generic risk management steps. Each of these steps should be taken in every distinct project phase.

This GeoQ approach has been initiated by the Dutch National Institute GeoDelft in 2000. It has been further developed since with many different parties, by its application on (parts of) all types of civil engineering projects in practice. GeoQ matches easily with existing risk management approaches, such as MARIUN in the UK and RISMAN in The Netherlands.

Finally, this lectures positions ground risk management in the landscape with ground engineering, natural hazard management, project management, quality management, and knowledge management.

### 3.3 *The human factor in geo risk management*

Giving detailed attention to the human factor in lectures on geotechnical risk management at a civil engineering department seems a rather innovative approach. The need for it has already become clear by the research of Bea (2006) and Sowers (1993), as mentioned earlier in this paper. For those readers not yet convinced, there is a citation of Brandl (2004):

> "There are no insurmountable weak soils or rock, there are only weak engineers".

This possible weakness of these engineers starts if there is no awareness of the role of the people factor in engineering in general and ground risk management in particular. Therefore, the concept of the individual professional, his or her inherent differences in risk perceptions, and how these may contribute to geotechnical risk management are explained during the first lecture hour. Some exercises with the students demonstrate how sound facts easily result into totally different interpretations. Table 1 is retrieved from Van Staveren (2006) and based on work performed by Clayton (2001), Kort (2002), and Koelewijn (2002). This table illustrates the effects of these differing engineering opinions in geotechnical analyses.

Table 1 shows that differences between geotechnical calculations, performed by different professionals, may vary a factor 5 to 10. The actual measured values of pile bearing capacity or settlements are positioned in-between the margins.

Table 1. Margins within geotechnical engineering (van Staveren, 2006).

| Geotechnical analysis | Calculated | | Measured |
|---|---|---|---|
| | minimum | maximum | |
| Pile bearing capacity (Clayton, 2001) | 1000 kN | 5400 kN | 2850 kN |
| Horizontal sheet pile deformation (Kort, 2002) | 50 mm | 500 mm | 100 mm |
| Slope stability safety factor (Koelewijn, 2002) | 0.36 | 1.65 | - |

As we are not able anymore to work on our own in today's demanding engineering and construction practices, the second hour focuses on *teams*. The concept of the team is introduced, with special attention to a variety of aspects. Examples are the differences between groups and teams, the hurdles to overcome before real team performance, the role of culture and risk communication in teams, the danger of groupthink, and so on.

Within the construction management process three types of team are in particular important: *expert* teams, *multi-disciplinary* teams and teams as *change agents*. The latter are for instance required for implementing risk management practices in project organizations. At the end of this lecture some words are dedicated to those parties we are performing for: public and private clients, as well as our societies.

### 3.4 *Lecture 4 – The GeoQ risk management process*

This lecture connects *thinking* about the GeoQ *concept* of the lectures before with actual *doing* by applying the GeoQ *process* in the remaining lectures. The six generic GeoQ steps of gathering project information, identifying risks, classifying risks, remediating risks, evaluating risks and finally mobilizing all relevant risk information to the next project phase are introduced and discussed. For each step a lot of tools are available and many of them are briefly introduced in this lecture. Here the students recognize some risk analysis tools from other MSc lectures as well, such as Fault Tree Analysis (FTA) and Failure Mode Effect and Criticality Analysis (FMECA). Now they may become aware of the very fundamental difference between risk *analysis* and risk *management*. The first is basically just a *tool*, however a very important one, in the entire risk management *process* that ideally continues from the early beginning to the end of the project's lifetime.

While the six GeoQ risk management *steps* are fixed, they should be applied one by one in a structured way, the six GeQ risk management *phases* are much more flexible. These phases are topic of the second lecture hour and they include the feasibility phase, the pre-design phase, the design phase, the contracting phase, the construction phase and the operation and maintenance phase. The contracting phase depends on the type of construction contract. Contracting will occur just before construction in case of conventional contracts. For design and construct type of contracts, the contracting phase is positioned before the design phase or even before the pre-design phase. For very large or rather small projects the number of project phases can be extended or combined. This does not effect the GeoQ process, as long as the six steps are strictly performed in each project phase.

### 3.5 *Lecture 5 – Six project phases and some tools*

Lecture 5 is the last rather theoretical lecture on ground-related risk management. This lecture explores a number of tools in more detail for five of the six distinguished project phases. Examples are site classification and scenario analysis in the feasibility phase, team-based risk identification and classification in the pre-design phase, and risk-driven site investigations in the design phase.

Some tools have their proven benefits well beyond ground-related risk management. An example is team-based risk identification and classification, by support of information and communication technology. In a typical setting, a team of professionals, either mono-disciplinary or multidisciplinary, participate a risk management session in a so-called electronic board room (EBR). Laptop computers and easy to use risk management software allows each participant to brainstorm anonymously on risk identification and classification. These individual professionals can build forward on the results of their team members, while unfavorable team effects are limited because any input remains unidentified by team members.

In the GeoQ phases of contracting and construction, risk management tools, such as contractual allocation of the risk of differing ground conditions by the Geotechnical Baseline Report (GBR) and the observational method, supported by online monitoring, are presented and discussed. Also for the operation and maintenance phase appropriate tools for ground-related risk management are ready available. Again, reference is made to Van Staveren (2006), because the two lecture hours of block 5 proved to be too short to discuss these tools as well.

## 4 GEO RISK MANAGEMENT - PRACTICE

### 4.1 *Introduction*

As mentioned before, the second part of the Geo Risk Management Lectures will only be briefly presented. These were provided by Martin van der Meer of Fugro, except the lectures 8 and 11, which were given by prof. Johan Bosch and dr. Gerard van Meurs.

### 4.2 *Lecture 6 – Risk and ground properties*

Lecture 6 focusses on ground and properties and specifically on dealing with the inherent uncertainty of these ground properties The first hour presents a number of problems resulting from these uncertain ground properties. These problems are related to a variety of aspects, such as engineering design codes, safety factors and the complex physical behavior of ground. The presented risk of exploding assumptions during a project, with resulting large margins in possible outcomes, should serve as a serious signal for any geotechnical professional.

The second hour presents a number of solutions for the problems, as raised during the preceding hour. Soil investigations schemes and methods are presented , including some guidance on dealing with representative values and geotechnical design values.

### 4.3 *Lecture 7 – Risk management and levees*

Lecture 7 presents an general overview on ground risk management and levees or dikes during the first lecture hour. This includes the ruling safety assessment for dikes in The Netherlands, dike reconstruction approaches and the risks of (new) structures, such as cables or pipelines, around or even in dikes, on the safety of the dike.

During the second lecture hour a few special topics on ground risk management and dikes are presented. An example is a full-scale test to verify the risk of the dike failure mechanism of uplift. Predicting of failure of a dike during the full scale test appears to be at least as complicated as to design a safe dike.

### 4.4 *Lecture 8 - Risk and underground construction*

The two lecture hours of block 8 are fully dedicated to one of the largest and probably most complicated underground projects under construction in The Netherlands to date: the North-South metro line in the historic Dutch capital of Amsterdam. After an introduction of this nearly 2000 million euro project the lecture presents geotechnical risk management aspects of the tunnel boring, the cut and cover construction of the very deep and narrow stations and the passage below the historical and sensitive building of the Amsterdam central train station.

### 4.5 *Lecture 9 - Risk and building projects*

This lecture on ground risk management and building projects has as the following subtitle: surviving the execution phase? It starts with presenting the risk profiles that can be expected for project with building pits in particular, including examples such as the risks of pile foundations. Monitoring during building pit construction is presented as a major risk remediation measure.

The second hour presents cases with feasibility checks, design dilemma's and execution risks, with specific attention to the important role of effective geotechnical data management during the entire project.

### 4.6 *Lecture 10 - Risk and infrastructure projects*

This lectures pays attention to a major risk factor for infrastructure projects, at least in deltaic area with soft soils: settlements. Higher (differential) settlements than anticipated cost additional money and time. However, also lower settlements than designed during construction will cause problems and additional costs. The two hours focus on how to deal with this settlement risk paradox, supported by a case study of a highway project.

### 4.7 *Lecture 11 - Geoenvironmental risk aspects*

The topic of the two hours of lecture 11 is fate and migration of contaminants in the ground. After presenting a few famous cases of soil pollution and their remediating measures in The Netherlands, some basic phenomena of ground and ground water in relation to characteristics of pollution are presented. This information serves as basis for three methodologies to manage geoenvironmental ground risk: the source-path-receptor concept, the isolate–control–monitor approach, and the flexible emission control concept.

### 4.8 *Lecture 12 - Some special issues*

The very last two lecture hours are used for presenting a summary of the preceding lectures, discussing and answering questions of the students. Furthermore, some guidance is provided for the preparation of the written and case-based exam. Within the exam, students should be able to apply the risk management principles, as presented in the lectures, in combination with their already achieved geotechnical engineering knowledge from other lectures of the MSc in Geoengineering.

## 5 CONCLUSIONS

During the first lectures, most of the MSc students showed difficulty with acknowledging the inherently different risk perceptions between people, even between apparently rational human beings, such as engineering students. It did shake their engineering world view to some extent.

It was therefore very rewarding to notice a change in student awareness and attitude during the lectures. Their understanding of the inherent differences of the client's, the engineer's and the contractor's risk perceptions increased, as was demonstrated by the questions and discussions.

One main conclusion can be drawn: the rather innovative combination of geotechnical risk *management*, the *people factor*, a lot of geotechnical risk *analysis* tools and many *cases* from practice, all blended in one new course, has been enthusiastically welcomed by the students. They showed serious motivation to apply this mixture in their professional practice. The future will teach us how our construction industries, and thus our societies, will benefit from this new and integrated approach of geotechnical risk management education.

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